Environment Design and Evaluation for Digitalized Main Control Room in Nuclear Power Plant

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Abstract

The purpose of the Environment Design (ED) for Main Control Room (MCR) of Nuclear Power Plant (NPP) is to provide crews with an optimal working conditions and spaces to be free from physical, physiological and mental stress as well as environmental discomfort. The ED was performed in three design areas: lighting design, interior design with color design, and human factor engineering design. Three design areas have been interactively cooperated in a way that each design specialist would share the objectives and concepts of the Environment Design for MCR in NPP.

The specialists for Human Factors Engineering design had a cooperatively important role in such a way to provide the guidelines for MCR design suitability of Interior and Lighting design considering the Human System Interface (HSI) safety concerns and then evaluate the results. This paper describes technical efforts by human factors engineer to create the best fit for MCR ED among several design proposals with the design recommendations, impacts, and contributions to NPP environment considering HFE guideline based evaluation and the previous environment design experiences.

KEYWORDS: Environment Design, Human Factors engineering, Main Control Room, Nuclear Power Plant,

Introduction

The analog or partly digital typed interface of main control room(MCR) in nuclear power plant (NPP) is gradually being replaced to the totally digitalized interface suitable for the digital environment. And also the more the computerized devices and procedures are used in the human system interface, the mental model of computer users has been more changed from analogue stereotype to digitalized one[3]. The digitalized system interface should be evaluated for the environment design (ED) suitability for digitalized environment.

The purpose of ED for MCR of NPP is to provide crews with an optimal working conditions and spaces to be free from physical, physiological and mental stress as well as environmental discomfort. NPP MCR such as SKN 3&4 in Korea and BNPP 1&2 in UAE are currently developed in such a way to employ the concept of the totally digitalized environment.

There are three main areas for the Environment Design: human factor engineering design, interior design with color design, and lighting design. As shown at Figure 1, these three design areas are interactively cooperated in a way that each design specialist would share the objectives and concepts of the Environment Design for BNPP 1&2.
Environment Design

Human factor engineering design had a critical role of the cooperation in such a way to provide the guidelines for MCR design suitability of Interior and Lighting design.

In order to assure quality product within limited resources and times, we had a design process with top-down and iterative steps as shown at Figure 2. Each process step had a feedback after the debriefing session until the consensus has been achieved among the technical groups.

BNPP 1&2 MCR in UAE should be an emulated model of APR1400 which is an advanced type of digitalized MCR such as SKN3&4 in Korea. Many issues involved in emulating APR1400 including vernacular design issue were collected and used to build the concept of BNPP1&2 MCR. In order to get the design fidelity of the resolved issues of BNPP1&2 MCR design, technical surveys and anthropometric data collection in UAE have been performed.

Based on the collected data and concepts, Interior design and illumination design alternatives for BNPP1&2 MCR were proposed by each technical group. The MCR design suitability for the proposed designs was evaluated by the HFE specialist according to the human factor engineering guidelines which were developed with the integration of NUREG based HFE guidelines. Finally, the best alternative design was selected after considerable iterative steps with safe-concerned feedbacks from debriefing session of technical groups.

A Human Factors Engineering (HFE) principles and guidelines have been applied to optimize the design and operation of Man-Machine Interface (MMI) between operators and their equipment in consideration of physical, psychological and cognitive aspects. However, it has been observed that operators complain about environmental discomfort in the MCR since the operators in the MCR experience excessive stress due to the environmental factors such as inappropriate interior and lighting system.

Since the HFE is an essential factor for the high fidelity performance of operators in the MCR, the adequate MCR environment design with HFE rules and guidelines is as much important to enhance the operability and reliability of the MCRs. Therefore, there has been a strong need to design a pleasant environment for the MCR to improve human performance of the operators.

The purpose of the Environment Design (ED) for the MCR of NPPs is to create an optimal working space to be free from physical, physiological and mental stress as well as environmental discomfort so that design preference survey and anthropometry measurement were conducted to optimize the BNPP 1&2 MCR design. Anthropometry measurement includes 18 points of subjects’ body influencing workstation configuration such as console height, slope, angle, field of view, clearance of leg and feet, and so on.

The anthropometric data collected from UAE people showed that there were not significant differences of anthropometry between UAE people and Korean so that we could employ and implement the reference plant’s MCR physical configuration design into BNPP 1&2 with a slight design change.

HFE Evaluation

HFE guidelines have been developed as a Verification & Validation tool for system design suitability and the style guidance tool for system design process. NUREG-0800 chapter 18 in NRC Standard Review Plan (SRP) describes the requirement for employing the evaluation model of NUREG-0711 as shown at Figure 3. NUREG-0711 recommends the use of HFE guideline such as NUREG-0700 for the V&V (verification and validation) of NPP system design suitability.

For the evaluation of the human factor design suitability for BNPP1&2 Environment Design, 65 human factor items of 22 categories in 4 design areas were selected and evaluated. 4 main design areas for the human factor evaluation include general design, illumination design,
Figure 3 NUREG HFE Evaluation Model

interior design, and color design. Details are as follows:

General design: 6 categories, 21 items
- Layout(6)
- Document organization(2)
- Storage(5)
- Supervisor Accessibility(2)
- Communication (5)
- Comfort(1)

Illumination design: 7 categories, 14 items
- Illumination level(3)
- Task area luminance ratio(1)
- Ambient illumination(4)
- Material reflectance(1)
- Reflective glare(1)
- Surface color(1)
- Luminaries(3)

Interior design: 7 categories, 26 items
- Consoles ergonomics(7)
- VDU layouts(3)
- Furniture(7)
- Interior design(1)
- Ambient noise(4)
- Thermal & humidity (2)
- Ventilation(2)

Colors Design: 2 categories, 4 items
- Color coding(2)
- Colored illumination(2)

The general methodology of design evaluation is to compare the HFE characteristics and functions with the criteria provided in the HFE guidelines.[1][2] 65 items from 22 categories in 4 designs were selected for evaluating the design suitability for the proposed environment design of BNPP 1&2 MCR.

Corresponding HFE criteria for each design area was reviewed and a decision made with a check mark and comment. There were four types of decision after HFE evaluation: OK, Discrepancy, N/A, and Return.

OK indicates that the aspect of HFE evaluation is acceptable. This evaluation should be given only if there is total compliance, i.e., only if every instance of the item being reviewed is fully consistent with the provisions of the guideline. Discrepancy indicates that the aspect of HFE evaluation under review is discrepant from the guideline: i.e., there is less than total compliance with the guideline. N/A was checked for individual guidelines that do not apply to the particular review. Return was checked when a guideline is applicable but the information needed to make the evaluation is not available. In this case, it makes a comment of what is needed to complete the evaluation.

Results

Through the environment design process considering UAE vernacular design, the best design for BNPP1&2 MCR was proposed as shown at Figure 4. The AHP survey results showed that more than half interviewees wanted Islamic-style MCR in color and spatial design. But some of the NPP design regulations about seismic design and usage of finishing material constrained and limited to apply the collected opinions for MCR design.

Illumination design output applying for HFE guideline was verified with illumination simulation software which showed that proposed illumination design was suitable for within a permissible range of HFE spec.

Interior design output created slight change of console height from the HFE evaluation so that the change would provide crews the safe and comfortable MCR environment.
Discussion

MCR is very important for a safe operation of nuclear power plants, so it requires strict design and maintenance for a proper lighting environment in accordance with the standards of ergonomic design. In particular, as the MCR of nuclear power plants is in the transition state of being digitalized, a visual environment created by lighting is closely related to the spatial design of MCR. Additionally, accurate and immediate readings of information on the instrumental panel are very important. By considering the characteristics of tasks, which involve long hours of visual work, this study suggests a comfortable lighting environment that does not produce glare.

A lighting design should consider the aspects of color and HFE since lighting is a part of interior design. MCR is considered to be a lighting environment that is closely related to all other spatial elements such as the form, material, and color of the interior, as well as with the readability and control of instruments. Therefore, a lighting design suggested by this study will focus on the construction of a visual environment that is appropriate for an advanced type of MCR by employing the concept of an interface space via LOHAS (Life of Health and Sustainability). It is to meet the needs of users, as well as to meet architectural needs. A lighting design should consider overall spatial elements of MCR such as interior and color collectively.

Based on the collected data and concepts, Interior design and illumination design alternatives for BNPP1&2 MCR were proposed by each technical group. The MCR design suitability for the proposed designs was evaluated by the HFE specialist according to the human factor engineering guidelines which were developed with the integration of NUREG based HFE guidelines. Finally, the best alternative design was selected after considerable iterative steps with safe-concerned feedbacks from debriefing session of technical groups[4].

In order to evaluate the appropriate number of HCI issues on working environment, many guidelines and technical papers related to evaluation issues have been collected, analyzed and transformed to electric database forms and then built on database management system to retrieve the appropriate issues for information display on VDT. From the DBMS system, the relevant evaluation issues and its hierarchy has been finally developed and validated through guideline integration based on the concept of human cognitive model process.

The design issues and resolutions from the finding may provide the cues for the designers and evaluators of the specific man machine interfaces of the system environment using digitalized devices.

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